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Tools for Assessing Performance Project
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Comparison of Texas Tech building wake data to diffusive model:

In FY21-Q4 LANL started diffusive wake model validation using the sonic anemometer measurements of the wake behind Texas Tech's rotating building.

The rotatable building located at Texas Tech's Reese Technology Center is approximately 14 m wide (width being defined as more normal to the wind than parallel), 9 m long (aligned more with the wind than perpendicular), and 4 m tall. By placing 29 sonic anemometers downwind of the building, see Fig. 1, this facility provided a chance to collect data concerning both the wake velocity deficit distribution in the downstream and crosssteam directions (relative to the mean wind) behind an isolated building. A preliminary comparison between this data and the recently-developed fast-running diffusive wake model, which was developed based on wind tunnel and LES (performed with JOULES) simulations, for the purpose of either validating this model of understanding potential persistent differences between the idealized wind tunnel or LES conditions and those of full-scale real world phenomena. For this preliminary exploration, we utilized the diffusive wake model implemented in the QUIC model.

The primary meteorological parameters governing the diffusive wake model are shown in Table 1, including the wind speed at building height (4 m) and the reciprocal Monin-Obukhov length

Table 1.

Time UTC	Atmospheric stability	Wind speed (WS) at height of building (H) (m/s)	Reciprocal Monin-Obukhov length (RMOL) (1/m)
11:50-12:00	Stable	2.60	0.03
12:40-12:50	Neutral	3.22	0
17:40-17:50	Unstable	3.95	-0.055

Figure 1: Locations of sonic anemometers deployed in the nominal wake (assuming southerly winds) at Texas Tech's Reese Technology Center.

(RMOL) as measured by the sonics upwind of the building on 7/17/2021. Based on upwind wind speed profile measurements under neutral conditions, the aerodynamic surface roughness of brush upwind of the building is 0.05 m and this is used for all three QUIC simulations. Below is a preliminary results using a small subset of the total data that has been acquired in this field experiment. A more in depth analysis using an agragation of the entire dataset will be performed in Q1 of FY22.

Figure 2 illustrates the measured centerline wind speeds at the building half height for all three atmospheric conditions as well as simulated results using the diffusive wake model. The diffusive wake model overestimates the downwind extent of the building wake compared to the observations for all thermal stabilities but the overestimation is less for stable conditions than it

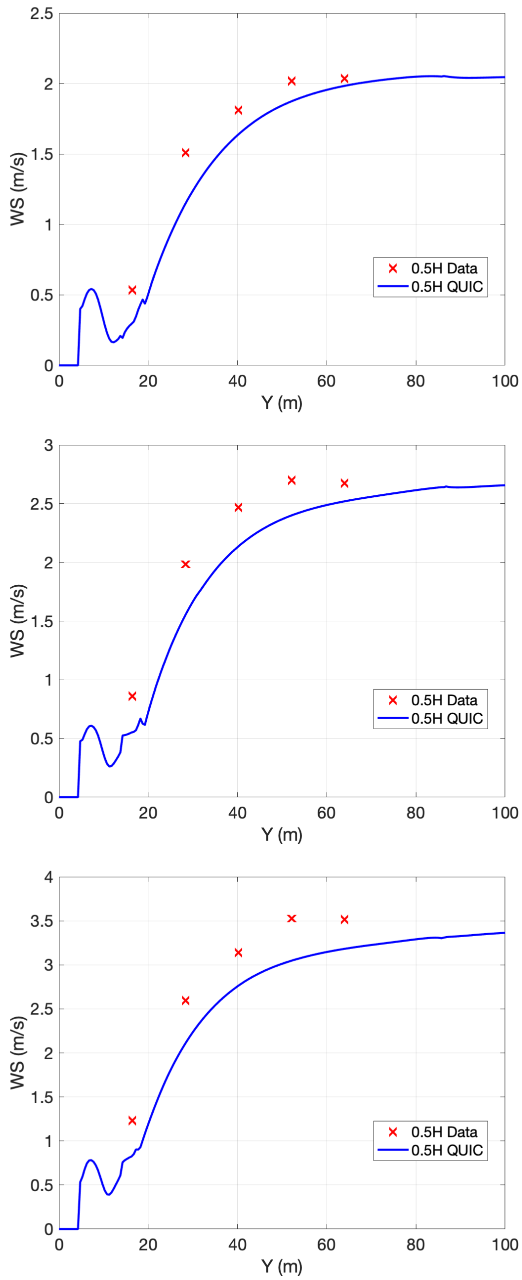

Figure 2. Comparison of the centerline wind speeds from the sonic anemometer measurements and QUIC diffusive wake model at 0.5H above the ground under southerly winds and thermally stable (top), neutral (middle), and unstable (bottom) atmospheric conditions.

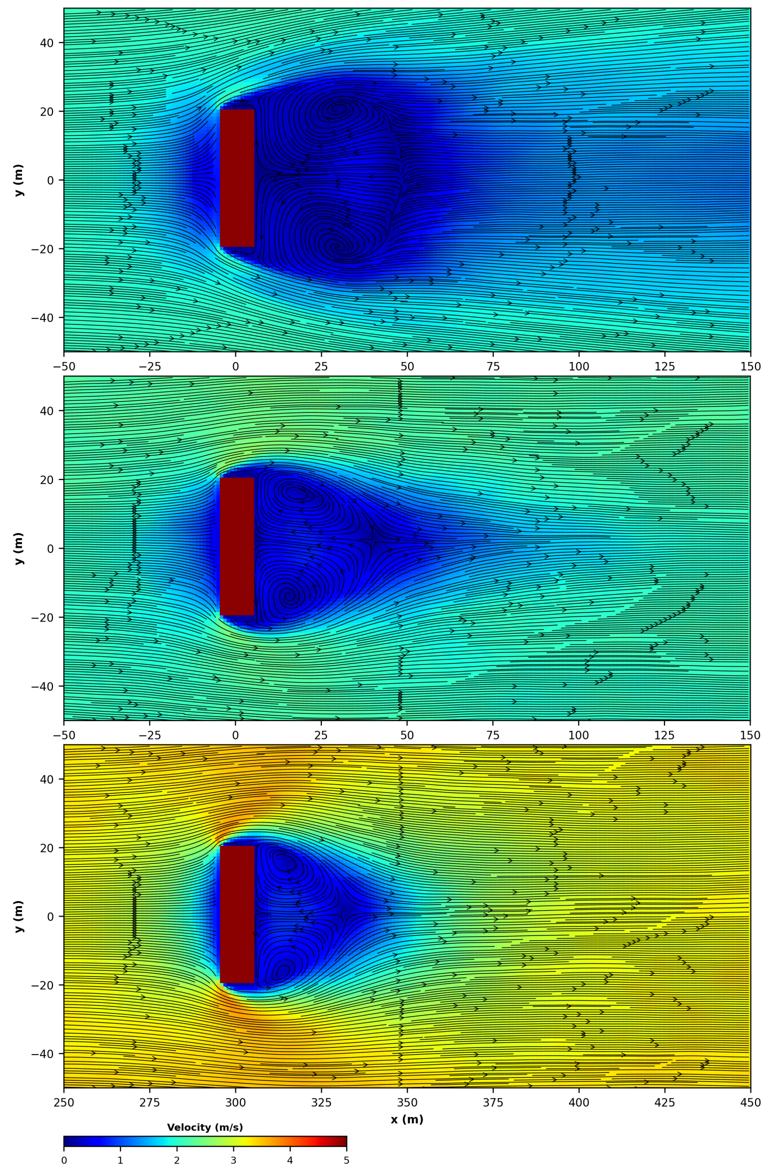

Figure 3. Wind speed contours and streamlines from 4H wide building from the JOULES model simulations at 0.5H above the ground under perpendicular winds and thermally stable (top), neutral (middle), and unstable (bottom) atmospheric conditions.

is for neutral and unstable conditions. For the three time periods used in this analysis, the downwind extent of the modeled and observed building wakes appear to be relatively insensitive to the atmospheric stability and only extend about 12H downwind of the rear face of the building. Wind tunnel measeurements by Kothari et al. (1979) indicate that the velocity deficit in the wake in stable stratification can extend more than 30H downwind of a model building. The diffusive wake model predicts the length of the wake, i.e., the point at which the velocity returns to the ambient levels and stops accelerating, to increase as the thermal stability transitions from stable through neutral to unstable. This is the opposite of what was expected from the JOULES data (see Figure 3). This suggests a potential issue in the machine learning algorithm or translation from Python to Fortran when the machine learning algorithms are incorporated into the QUIC model. This will be investigated and corrected in FY2022 Q1.

Figure 4 shows the lateral profile at the building half height along the 3H downwind row of sonics. The data shows that the lateral spread decreases at 3H downwind of the building as the atmospheric stability transitions from stable to unstable conditions. The diffusive wake model has the opposite trend and the lateral spread increases from stable to unstable conditions. Subsequently the model underestimates the lateral spread for stable cases and overestimates it for unstable cases. The trends in the lateral spread in the JOULES simulations agree with the measurements, with wider lateral spread under stable conditions and less lateral spread under unstable conditions. This is likely another symptom of the issue found in the behavior of the downwind extent of the wake with thermal stability and this will be corrected.

The vertical profiles of sonics directly behind the building (along the extended centerline) at 3H and 6H downstream are shown in Figures 5 and 6, respectively. The diffusive wake model performs relatively well at 0.5H but significantly overpredicts the vertical diffusion of the wake above the top of the building at the locations measured. The general trends exhibited by the model agree with the measurements. The peak velocity deficit decresses and the vertical spread of the wake increases with downwind distance. Figure 7 shows JOULES simulations of a 40 m wide (crosswind), 10 m long (streamwise), and 10 m tall building, so it is not identical to the Texas Tech building but has the closest width to height ratio from the suite of JOULES simulations. The measurments in Figures 5 and 6 show the wake returning to the ambient levels as low as 1.5H at 3H downstream and near 2H at 6H downstream. With the 10 m height of the building, the JOULES simulations do not return to the ambient wind profile until a height of 30 m or 3H. Therefore, the overestimation of the vertical extent of the wake is also found in the JOULES simulations and is unlikely to be a result of the issues that have caused the incorrect behavior with varying thermal stability.

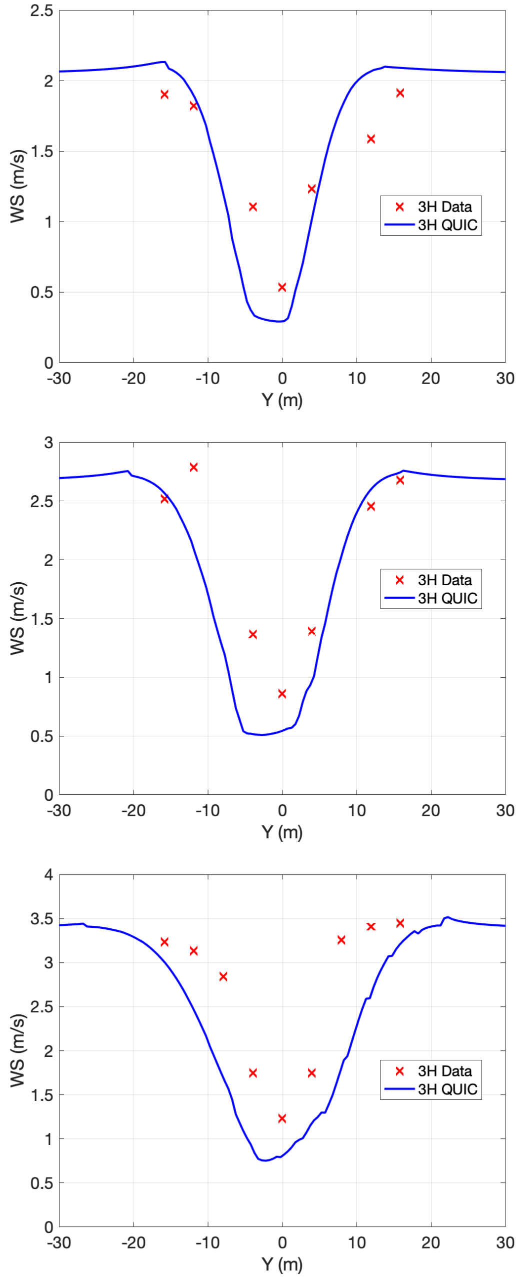

Figure 4. Comparison of the lateral profile of wind speeds from the sonic anemometer measurements and QUIC diffusive wake model at 3H downwind of the building and 0.5H above the ground under nominally perpendicular winds and thermally stable (top), neutral (middle), and unstable (bottom) atmospheric conditions.

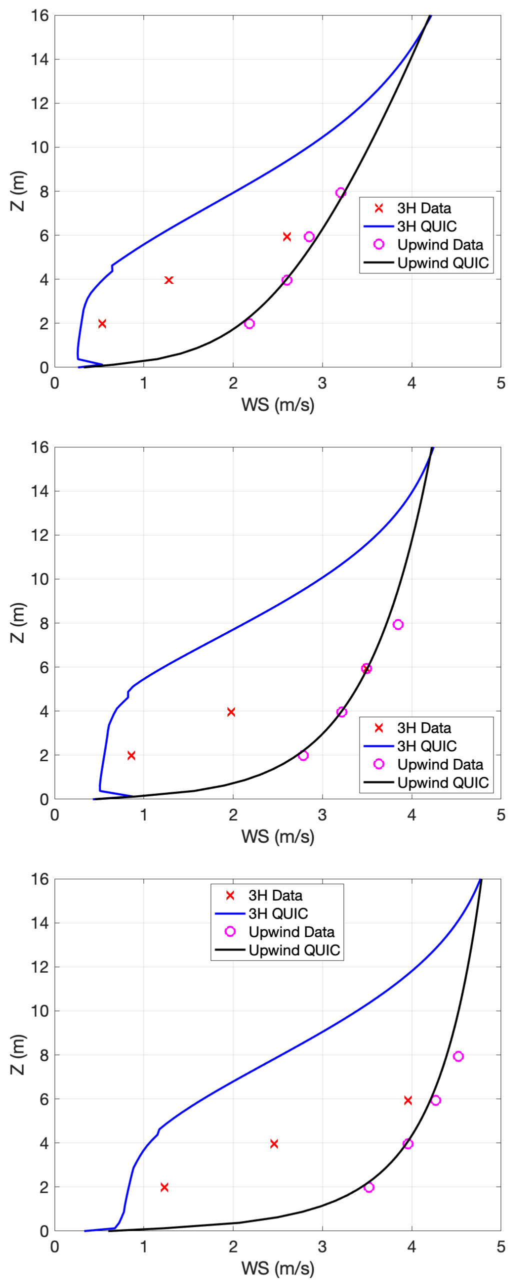

Figure 5. Comparison of the vertical profile of wind speeds from the sonic anemometer measurements and QUIC diffusive wake model along the centerline at 3H downwind of the building under nominally perpendicular winds and thermally stable (top), neutral (middle), and unstable (bottom) atmospheric conditions.

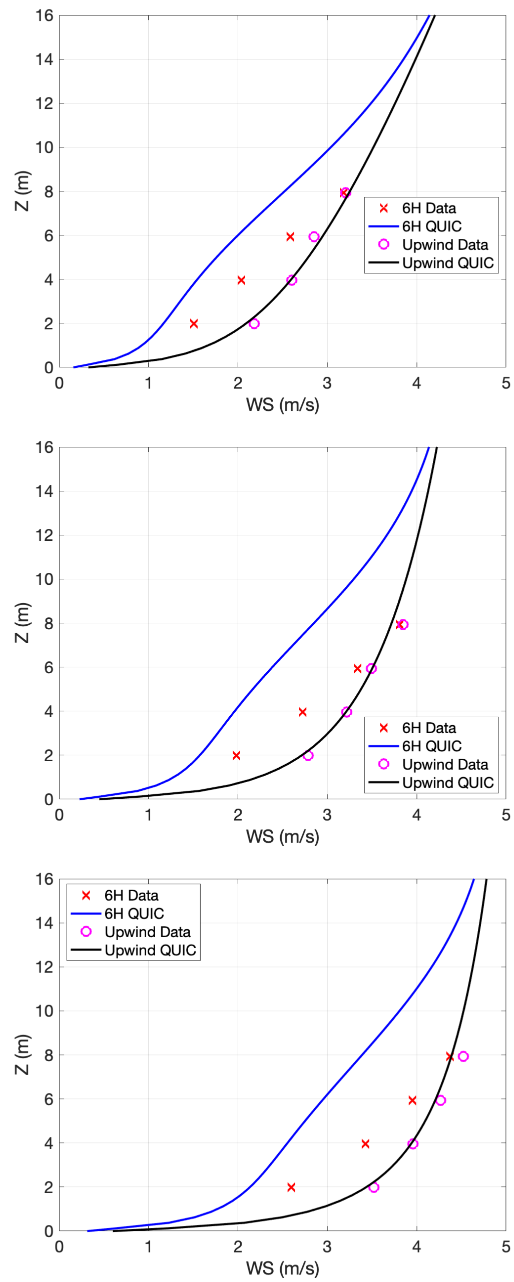

Figure 6. Comparison of the vertical profile of wind speeds from the sonic anemometer measurements and QUIC diffusive wake model along the centerline at 6H downwind of the building under nominally perpendicular winds and thermally stable (top), neutral (middle), and unstable (bottom) atmospheric conditions.

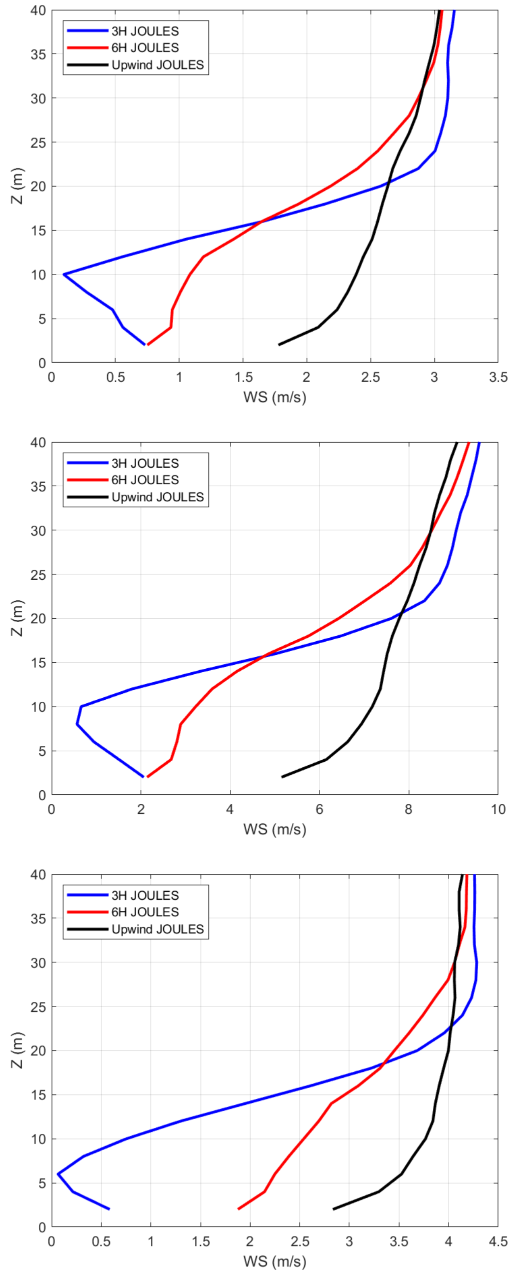

Figure 7. Comparison of the vertical profile of wind speeds from the JOULES model along the centerline at 3H and 6H downwind of the building under nominally perpendicular winds and thermally stable (top), neutral (middle), and unstable (bottom) atmospheric conditions.

Preliminary Conclusions:

While we are just beginning to analyze the measurements of the wake of the Texas Tech building and only examined three 10-minute periods, this experiment has already produced interesting results. Unlike the JOULES simulations, the measured downwind extent of the building wake was relatively insensitive to atmospheric stability. Additionally, the vertical extent of the wake was significantly overpredicted in the JOULES simulations and subsequently the diffusive wake model in QUIC, which was calibrated based on JOULES simulations. It is currently unclear why JOULES predicts such large vertical spread of the wake as it was able to reproduce similar results ($\leq$ 2H) to the EPA wind tunnel experiments in previous investigations. It could be a fundamental difference in the characteristics of the turbulence that exists in a real atmospheric boundary layer that is difficult to replicate in wind tunnel models. The relative height of the boundary layer compared to the height of the building will be much larger in the atmosphere than is possible to replicate in a wind tunnel. This will affect the largest turbulent length scales found in the ambient flow and may act to add more turbulent mixing in the wake causing it to return to ambient conditions much faster than will be found in wind tunnel studies. As the primary goal of these models is to replicate the behavior of building wakes in real-world conditions, bridging this knowledge gap is key to the usefulness of the model. Additional investigation will be required to validate this hypothesis. We will perform a more extensive analysis of the data in FY22-Q1 where we will sort the data into different wind directions, wind speeds and thermal stabilities and will average the data from multiple time periods to ensure that the results are not anomalies of an individual 10 minute period.

References:

Kothari, K.M., Peterka, J.A. and Meroney, R.N., 1979. *Stably stratified building wakes* (Doctoral dissertation, Colorado State University).